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Effects of wind turbines and other physical elements on field utilization by pink-footed geese (*Anser brachyrhynchus*): A landscape perspective

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Abstract

The effects of wind turbines and other physical landscape elements on field utilization by wintering pink-footed geese (*Anser brachyrhynchus)* were studied in a Danish farmland landscape. Within the study area geese were feeding on pastures, which together with cereals were the main crop types. Apart from wind turbines a variety of potentially disturbing landscape elements was present, e.g., high-power lines, windbreaks, roads and settlements. Patterns of field use were assessed by measuring goose dropping densities along transects perpendicular to wind farms (with turbines in clusters and in lines) and other landscape elements. Local effects were expressed in terms of 'avoidance distance', i.e., the distance from a given landscape element to the point at which 50% of maximal dropping density was reached. The spatial distribution of landscape elements within an eight km radius from the goose roost was determined from aerial photographs. The area occupied by various elements, together with the adjacent zones which were not available to geese due to their associated avoidance distances, were quantified using Geographic Information System (GIS).

The avoidance distance of wind farms with turbines in lines and in clusters were ca 100 m and ca 200 m, respectively. Geese did not enter the area between turbines within the cluster. At the landscape level, the combined effect of physical elements other than wind turbines caused an effective loss of 68% of the total field area (40 km^2). Wind turbines caused an additional loss of 4% of the field area. However, of the remaining area available to geese (13 km^2), wind turbines caused a loss of 13% of the total area. The habitat loss per turbine was higher for the wind farm with turbines arranged in a large cluster than for wind farms with turbines in small clusters or lines. This difference was mainly due to the fact that wind farms in small clusters or with a linear layout were generally placed close to roads or other elements with existing associated avoidance zones, whereas the large cluster was placed in the open farmland area. The avoidance zones associated with physical elements in the landscape do not take into account possible synergistic effects and, hence, actual field areas affected are likely to be minimum estimates. Implications of these findings for planning of wind farms in areas of conservation interest to geese are discussed.

Introduction

The planning and establishment of wind turbine farms in open landscapes has given rise to much controversy relating to bird conservation issues in many European countries, both with regard to collision risks and disturbance effects (e.g., Percival 1999). However, very little published quantitative information exists about the disturbance effects of wind farms, on birds especially outside the breeding season (swans, ducks and waders: Winkelman 1989, 1992; Kruckenberg and Jaene 1999; sea ducks: Guillemette et al. 1998, 1999). Hence, most environmental impact assessments and guidelines for planning of wind farms in areas of interest to birds outside the breeding season are founded on insufficient scientific data. Furthermore, the stud-

ies of Winkelman (1989, 1992), Kruckenberg and Jaene (1999) and Guillemette et al. (1998, 1999) have focused on local effects, with no assessment of the wider implications of wind farms at the landscape, or regional, level.

This study examines the disturbance effects of wind farms on habitat utilization by wintering pink-footed geese (*Anser brachyrhynchus)* in a Danish farmland area. We assess the local isolated effects of wind farms and other physical elements, such as windbreaks and power lines. Based on an assessment of the combined habitat loss due to avoidance of various physical elements at the landscape level, we quantify the added loss of goose feeding habitat due to avoidance of wind farms. We discuss implications for planning of wind farms at a landscape level.

Study area

The study was carried out during spring 1998 in Vejlerne in northwest Jutland, Denmark (Figure 1), which is used as a wintering and spring staging area of pink-footed geese from the Svalbard breeding population. The western part of Klim Fjordholme is part of an EU Special Protection Area and Ramsar Site that includes Vejlerne (Anon 1996). In mild winters, geese arrive during December and numbers peak during February-March. The last flocks leave the area early in May. Numbers have increased drastically, from a peak of less than 1000 individuals in the early 1980s to 11 000 in the late 1990s (Madsen 1998). Hence, Vejlerne has become one of the most important staging areas of the population which totals 34 000–37 000 geese (Madsen et al. 1999).

At Vejlerne, the geese roost on shallow water lakes or in marshes within the Vejlerne nature reserve. During daytime, the geese make foraging flights to adjacent farmland fields outside the reserve (Figure 1). Klim Fjordholme east of Vejlerne is one of the most important feeding areas, supporting up to 6000 foraging pink-footed geese. During winter and early spring, the geese mainly feed on cultivated grassland, supplemented by winter cereal fields and stubble fields (Madsen 1996). During late winter and spring 1998, geese were only observed to be feeding on pastures. It was recorded that the geese flew up to a distance of eight kilometers from the roost site to the feeding grounds (pers. obs.).

Klim Fjordholme is a former marsh (< 3 m asl) which has been drained and cultivated for agricultural purposes. It is a mixed farmland with a majority of pig farms, with pastures, winter and spring cereals and rape as dominant crop types. Within the eastern semicircle of the eight km zone around the goose roost (Figure 1), the geese feed in a 44 km^2 farmland area. Pastures, the main foraging grounds of the geese, where interspersed all over this area. The landscape is intersected by roads with varying traffic intensity, windbreaks (either coniferous or deciduous trees in lines) and two high-power lines. Apart from two villages, most settlements are solitary farms.

A total of 61 mostly medium sized wind turbines (200–600 kW, tower height 25–50 m) have been built within the study area in recent years. Turbines are either solitary or situated in farms in lines or clusters (Figure 1). All wind farms consist of five wind turbines or less, except for one farm consisting of 35 turbines.

Material and methods

Avoidance distances towards physical landscape elements

Field utilization by pink-footed geese was assessed by counts of dropping densities in pastures in early April 1998. Since geese produce droppings at short intervals during feeding (pink-footed geese feeding on pastures at intervals of about 5 min (Madsen 1985a)), the density of goose droppings is an indicator of field utilization. During normal weather conditions, droppings disintegrate within 3–4 weeks due to precipitation; however, in April 1998, goose droppings had accumulated for two months, as the last heavy rainfall had occurred in early February. Hence, the droppings reflect field utilization during February-March which is the period of peak occurrence of geese.

The ‘avoidance distance’ from a given physical element was defined as the distance at which dropping density reached 50% of the maximum density along a transect perpendicular to the object. This equals the field area effectively lost, assuming that goose usage increases linearly from zero to 100% with distance from a given physical element. For wind turbines, high-power lines and windbreaks, the avoidance distance was assessed by field data. We discriminated between wind farms with turbines positioned in clusters and those in single line. The avoidance distance was assessed for a large cluster and a line wind farm consisting of 35 600 kW turbines (tower height 45 m) and five 225 kW turbines (tower height 31 m), respectively (Figure 1). In both wind farms turbines were

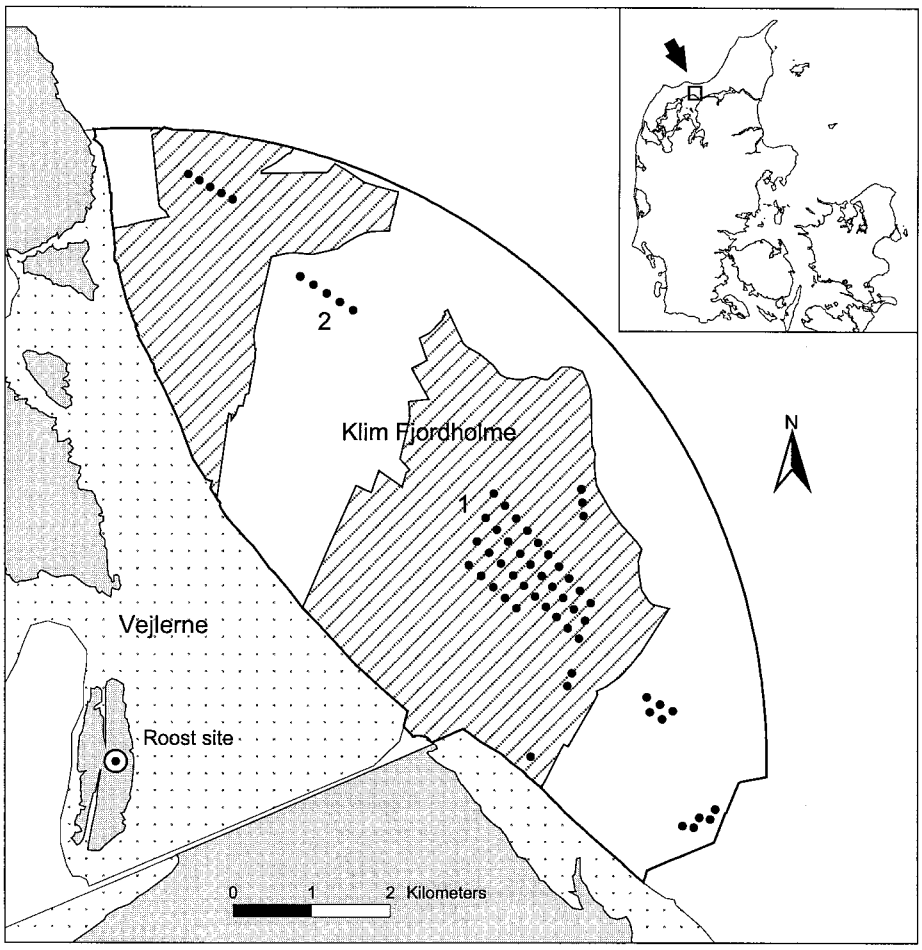

Figure 1. The position (in north Denmark) and extent of the Klim Fjordholme study area with the presence of wind turbines (black dots). The area was utilized by geese roosting overnight on a lake (large dot) in the nature reserve Vejlerne. Field type composition was determined in two sub-areas (hatched). Numbered wind farms show areas where avoidance distances were assessed.

positioned at intervals of 200–300 m. For roads, data from a previous Danish study on spring staging pink-footed geese were used (Madsen 1985b). Roads were categorized in two types: large; i.e., hard surface roads ($\geq$3 m width) and small; i.e., small hard surface roads ($<$3 m width) or loose surface roads. For forests and settlements, no data were available, and it was assumed that avoidance distances were similar to those of windbreaks and large roads, respectively.

For each of the studied landscape elements 2–3 perpendicular transects were laid out at intervals of about 200 m. Along each transect droppings were counted in plots of 1 m radius (3.14 m^2) at intervals of 25 m. Transects were only placed in homogeneous pastures. In the case of the cluster wind farm, it was not possible to place transects within the available pastures which were not interfered by windbreaks or power lines. Therefore, we initially assessed the effects of windbreaks and power lines, and then subsequently the effect of wind turbines excluding parts of transects within the avoidance distance of the other elements. In addition, two transects were placed between turbines of the large cluster wind farm to see whether geese used the space between turbines.

Regional presence of landscape elements

A map of the regional distribution of fields, settlements, roads, power lines, windbreaks and forests was generated on the basis of 1:25 000 digital orthophotos (Kampsax – Geoplan) dating from 1995. The extent of each element was digitized, stored and processed by means of a GIS (Geographical Information System). For the purpose of this study, settlements include

intersecting roads and windbreaks within or on their perimeter, and forests include interior settlements and roads.

The total area of pastures was estimated from field data on crop composition collected in two sub-areas of 15.2 and 7.1 km^2, respectively, comprising in total about 50% of the study area (Figure 1).

Regional habitat loss

The effect of landscape elements on the regional availability of feeding areas was assessed for each element separately and for all elements in combination, excluding and including wind turbines, respectively. Based on the avoidance distances found for each object, an avoidance zone was assigned around each landscape element by means of GIS. The part of this avoidance zone extending into fields was then extracted and the affected field area calculated. For wind farms, effect of access roads established in connection to the construction were included in the assigned avoidance zone. As avoidance zones related to two or several landscape elements frequently overlapped, the combined effect of landscape elements was calculated by merging their individual avoidance zones.

The avoidance zone assessed for all landscape elements in combination was checked against actual data on field utilization by geese for a selection of 28 pasture fields. Utilization was determined by the presence or absence of droppings in field centers, based on three randomly placed 3.14 m^2 plots.

Results

Avoidance distances of landscape elements

The effect on pink-footed geese field utilization of windbreaks, power lines and wind turbines in lines and in clusters, respectively, are illustrated in Figure 2. For all landscape elements field utilization increased markedly within a relatively narrow distance zone, after which a leveling off was observed. The avoidance distance of windbreaks was between 100 and 125 m for both transects. For power lines the avoidance distance varied between 25 and 75 m. For wind turbines the effect seemed to differ according to the type of wind farm; the avoidance distance of turbines on a line varied within the 75–125 m interval, compared to 175–200 m for turbines in a cluster. Along two transects within the large cluster wind farm, no goose droppings were found.

Table 1. Avoidance distances of various landscape elements in relation to field utilization of pink-footed geese.

Landscape element	Avoidance distance (m)
Wind turbine	
Cluster	200
Line/single	100
Power line	50
Windbreak	100
Road	
Large	150[a]
Small	50[a]
Settlement	150[b]
Forest	100[b]

[a]Derived from Madsen (1985b).
[b]Assumed, see Material and methods.

Table 2. Areas occupied by avoidance zones of pink-footed geese in relation to various landscape elements in isolation, and the corresponding percentages of the total field area (39.95 km^2) in Klim Fjordholme.

Landscape element	Field area affected	
	km^2	%
Isolated effects:		
Settlement	10.795	27.0
Road		
Large	8.393	21.0
Small	4.090	10.2
Power line	1.730	4.3
Windbreak	18.450	46.2
Forest	5.777	14.5
Wind turbine		
Cluster	2.851	7.1
Line/single	0.545	1.4
Combined effects:		
Without wind turbines	27.293	68.3
With wind turbines	28.909	72.4

Table 1 lists the avoidance distances applied for the studied landscape elements, rounded to the nearest 50 m interval, together with the distances applied for other elements. Madsen (1985b) found avoidance distances of 120 m for roads with traffic volumes of 20–30 cars per day and 10 m for roads with less than 1 car per day. As the traffic volumes for the two categories of roads used in this study were judged to be

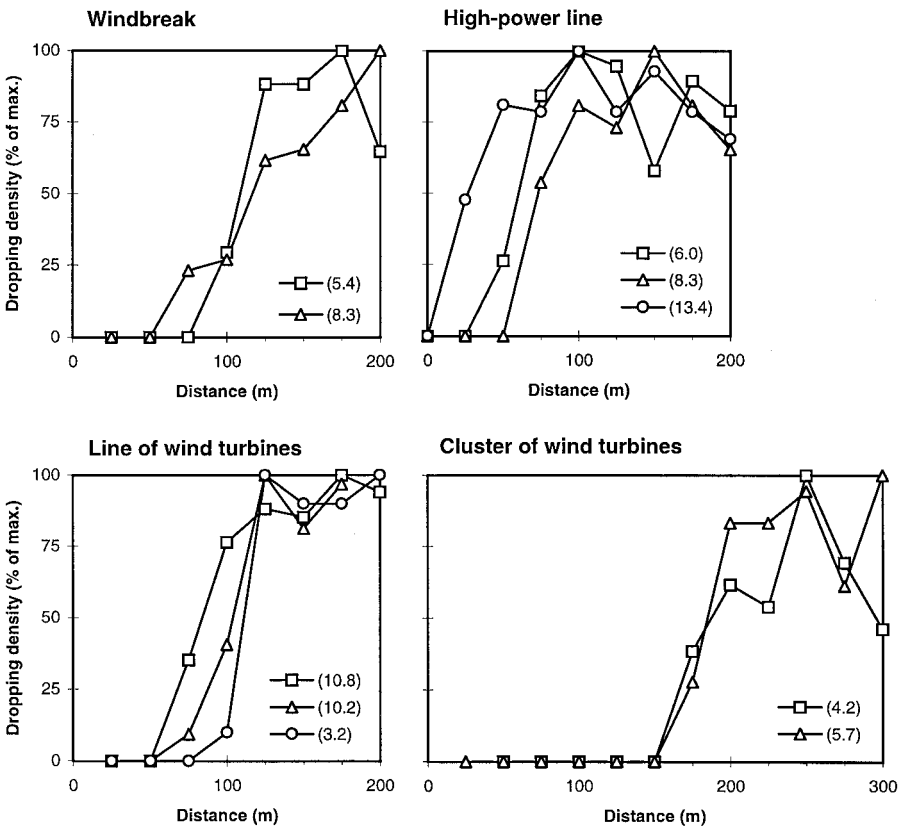

Figure 2. Field utilization by pink-footed geese in relation to distance from windbreaks, high-power lines and wind turbines on lines and in clusters. For each plot goose utilization was expressed as the percentage of the maximum dropping density per transect (shown in brackets, per square meter).

somewhat higher compared to the roads studied by Madsen (1985b), we applied an avoidance distance of 150 m for large roads and 50 m for small roads, respectively.

Regional habitat loss

The total area used by the geese east of Vejlerne comprised 44 km^2, of which fields covered 40 km^2. The presence of the various physical factors affecting field utilization within this area is shown in Figure 3. When we applied avoidance distances to each physical element in isolation, windbreaks were responsible for the largest habitat loss (46.2% of total field area), followed by settlements and large roads (27.0% and 21.0%, respectively) (Table 2). Wind farms with turbines positioned in clusters and wind farms with turbines in lines or solitary turbines caused a loss of 7.1% and 1.4% of the total field area, respectively, giving a combined total for wind turbines of 8.5%.

To evaluate the effect of wind turbines on the regional availability of fields, we first assessed the combined effect of other landscape elements, and then superimposed the effect of wind turbines (Figure 4). Disregarding the effect of wind turbines, it appeared that large parts of the study area, especially to the northwest and southeast, were already effectively lost to the geese by the disturbing effects of other landscape elements. The combined effect of these elements caused a total reduction of the available field area of 68.3%. Including the effect of wind turbines the overall loss of field area increased to 72.4%.

Before taking wind turbines into account, the total field area functionally available to geese was 12.66 km^2. Wind turbines caused a loss of 12.8% of these (Table 3). For the large part this was attributed to the effect of the large cluster wind farm, accounting for 10.0% of the additional field area lost to wind turbines. When calculating the additional field loss per wind turbine for wind farms with different layouts, the large cluster wind farm tended to cause relatively more

Figure 3. The presence of physical landscape elements affecting field use by pink-footed geese in the Klim Fjordholme study area.

habitat loss than both the small cluster wind farms and turbines in lines or singles (Table 3). However, large variation was observed within the group of turbines in lines and singles. This was mainly attributed to the two wind farms with five turbines in line in the northern part of the study area having widely different effects on field loss: the avoidance zone of the northernmost farm was fully embedded in the avoidance zones of other landscape elements, whereas almost the entire avoidance zone of the southernmost farm constituted added field loss (Figures 3 and 4).

In the two sub-areas where field type composition was checked, pastures made up 31.5% and 30.6% of the field area, respectively. Extrapolating the mean percentage of pastures from these subareas (31.0%) to the level of the study area gives an estimated total pasture area of 12.4 km^2. Decreasing this area by 72.4% (see Table 2), assuming that pastures made up a representative subset of fields in the way they are affected by physical landscape elements, this leaves an available goose feeding habitat of 3.4 km^2, equivalent to 7.7% of the study area.

The estimate of habitat loss based on the combined avoidance zones for all landscape elements, including wind turbines, was checked against actual goose utilization for 28 pastures fields. Of 13 fields in which the avoidance zones covered the centers, two fields were utilized by the geese and 11 were not. Of the 15 fields

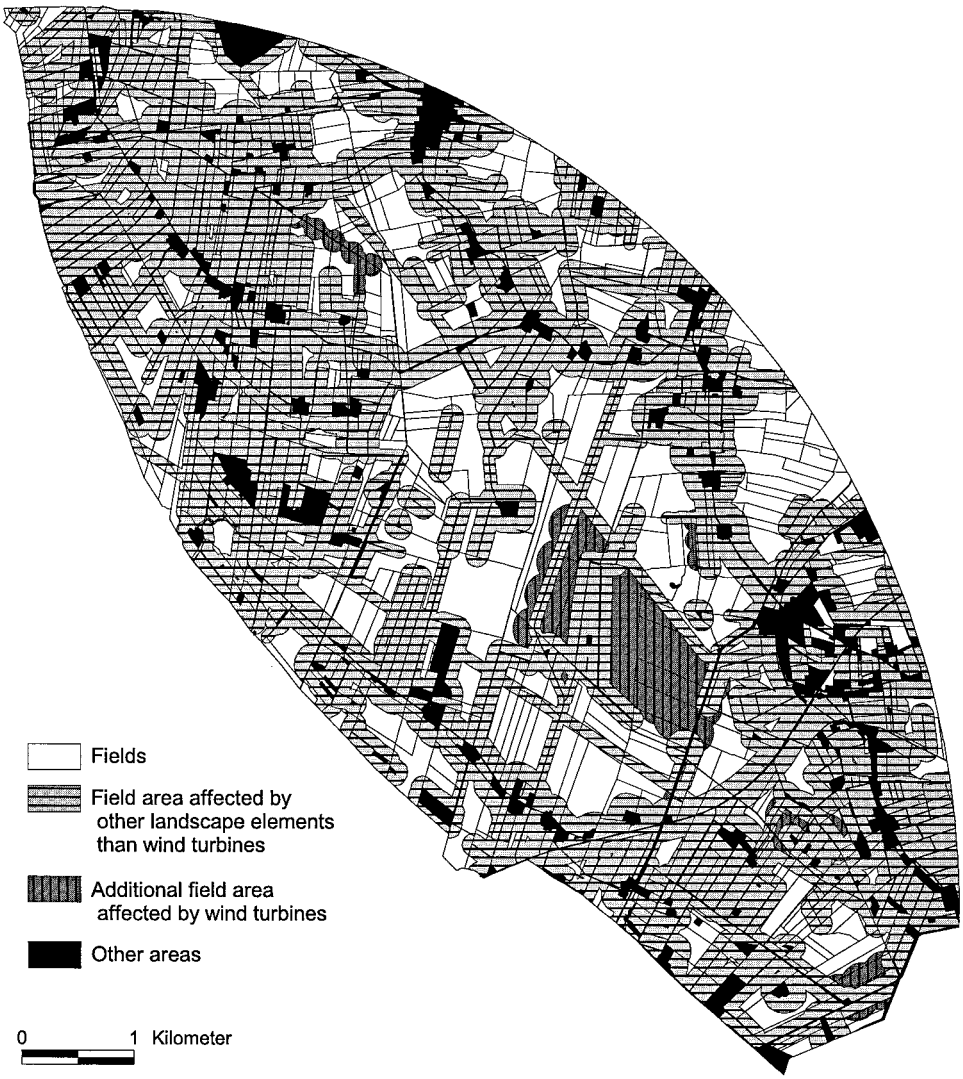

Figure 4. Regional field areas disturbed by physical landscape elements excluding wind turbines and the added field area lost to wind turbines. For positions of wind turbines and presence of other landscape elements, see Figure 3.

Table 3. Additional field area lost due to avoidance by pink-footed geese in relation to wind turbines, overall and for different layouts of wind farms, in absolute terms and relative to the field area unaffected by other landscape elements. In addition, the additional habitat loss per wind turbine is compared for the different layouts of wind farms (means with ranges in brackets).

Wind farm		Additional field area lost			
Layout	Locations	In total		Per wind turbine	
	(no. of turbines)	km^2	%	km^2	
Large cluster	1 (35)	1.259	10.0	0.035	
Small cluster	2 (10)	0.162	1.3	0.016	(0.012-0.020)
Line/single	5 (16)	0.195	1.5	0.009	(0.000-0.031)
Total		1.616	12.8		

where the avoidance zones did not cover the centers, however, 13 fields were utilized by the geese and only two were not. The observed proportion of fields used was significantly different for the two categories of fields ($\chi^2 = 14.23$, df $= 1$, $p < 0.001$).

Discussion

Due to the composite nature of the landscape, we were only able to obtain relatively limited data on the actual avoidance distances of wind farms in relation to foraging pink-footed geese. The results suggest that wind turbines placed in clusters created larger avoidance zones than turbines in lines. This was possibly due to the three-dimensional visual effect of clusters, but also the somewhat larger turbines in clusters may have contributed to the increased avoidance. The avoidance distances for wind turbines lie within the range found for geese: 25 m for barnacle geese (*Branta leucopsis)* (Percival unpubl. in Percival 1999) and 400–600 m for white-fronted geese (*A. albifrons*) (Kruckenberg and Jaene 1999), and compares to what has been found for swans (200 m: Winkelman 1989). For windbreaks the avoidance distance found in this study was somewhat longer than previous distances reported for pink-footed geese (ca 50 m: Madsen 1985b). Apart from species-specific differences, the degree of disturbance generated by a given physical elements may be influenced by a number of factors, such as flock size, hunting activity, the presence of other elements and time of year (see Fox and Madsen 1997). Therefore, avoidance distances are likely to be highly dependent on the given conditions.

Of a total field area of 40 km^2, only approximately 13 km^2 (32%) was potentially available to pink-footed geese, taking into account effects of landscape elements, other than wind farms. Including the effect of wind farms the field area available was further reduced to approximately 11 km^2 (28%). Taking the habitat preference of the geese into account, i.e., pastures, the available feeding area were about 4 km^2 (8%). The method by which habitat loss was derived, based on fixed avoidance distances around each element, is crude and not free from error. However, field validation showed that the method provided a reasonably realistic estimate of which fields were used by the geese. Madsen (1985b) showed that in fields surrounded by physical elements to more than one side, e.g., a field surrounded by windbreaks, the minimal width of fields accepted by pink-footed geese was >500 m, i.e., exceeding what was expected by addition of the avoidance distance of each element from each side. This synergistic avoidance effect reducing field use was not taken into account in this study, and will probably further reduce or eliminate the use of isolated small patches of fields shown as available (Figure 4). A synergistic effect of the large wind farm on the one side and the main road on the other side may also explain the observed absence of goose use of large fields southeast of the farm. Likewise, a synergistic effect between the large wind farm and the northerly power line may have caused the unexpected lack of use of fields north of the wind farm. However, the issue of synergistic effects merits more research based on a larger data set.

Wind farms caused an additional habitat loss equivalent to 4% of the total field area, but 13% of the available field area. In total, the large wind farm consumed most of the area lost to wind turbines. Comparing the proportional effect of different types of wind farms, also the additional habitat loss per turbine was highest for the large wind farm versus wind farms in small clusters and lines, which caused comparable habitat loss. One factor that contributes to this difference is the observed longer avoidance distance for wind farms in clusters compared to lines. However, the main factor responsible for this wind farm related pattern of habitat loss is the type of landscape in which it was positioned. The large wind farm was located in an area which was previously largely undisturbed by other landscape elements, whereas the smaller wind farms were mostly placed in areas already highly disturbed by other elements. Therefore, the differences in habitat loss per turbine mainly reflects a ‘size effect’, as large wind farms inevitably will tend to be placed far from settlements in open landscapes, which consequently have low densities of disturbing physical factors.

Since two of the wind farms were established in relatively undisturbed parts of the landscape (the large wind farm and a wind farm with turbines in line), they not only caused a direct quantitative habitat loss but also a fragmentation, which may further reduce goose usage. This was especially notable for the large wind farm, as this was placed in the largest open area in Klim Fjordholme. Hence, the open area was fragmented into smaller field units, which are not as suitable for larger flocks of pink-footed geese as the larger fields. For example, in situations when a flock of geese is flushed due to disturbance, lack of open areas may reduce refuge options within the area. Further-

more, larger flocks have longer escape flight distances than smaller flocks (Madsen 1985b), which further reduces the use of small field units.

Management implications

This study shows that the disturbance caused by wind farms, assessed by the avoidance distance in isolation, is relatively minor (≤200 m) in relation to foraging pink-footed geese which are suggested to be one of the most disturbance sensitive goose species with generally long (although variable) escape flight distances (Madsen 1985b). However, to assess the effect at a larger spatial scale, it is necessary to know the available foraging area. In the Klim Fjordholme case, the effective habitat loss due to wind farms was measurable at the landscape level; the wind farms not only caused a direct quantitative loss of habitat, but probably also an additional loss due to fragmentation of the open landscape. However, the wind farms in Klim Fjordholme were not critical to the overall conservation status of the site, judged by the fact that goose numbers increased during the 1990s, i.e., during the period when most of the wind farms were built. In other areas with more restricted space and available habitat, wind farms may have a larger effect. In this context, it might be noted that although wind farms are not allowed to be constructed within Danish EU Special Protection Areas, this has no importance for the majority of geese, which feed in cultivated landscapes.

From a goose site conservation perspective, the type of wind farm offering least impact in terms of field utilization is turbines in lines or in small clusters, as these may be positioned in conjunction to existing physical elements, such as roads, windbreaks or buildings. Large cluster wind farms will tend to coincide with the areas most preferred by the geese, i.e., the open and least disturbed landscape. Furthermore, it should be considered that any new access roads will cause additional habitat loss. Exactly which configuration (i.e., line or cluster) of wind turbines is offering least impacts in a given situation may be influenced by other factors than habitat loss. Other issues raised in relation to wind turbines are the risk of collision (e.g., Winkelman 1989), and the potential barrier effect of long lines of turbines (Dirksen et al. 1998).

The application of GIS and avoidance distances of different landscape elements in relation to flocking waterbird species such as geese provide a useful tool to visualize and assess potential impacts of wind farms and other physical installations at the landscape level. This offers a possibility already in the planning stage to mitigate potential effects of wind farms on waterbirds, thus reducing conflicts with conservation interests. Impact assessments should not only consider the direct quantitative loss of habitat but also fragmentation and possible synergistic avoidance effects of physical elements, necessitating a landscape ecological approach.

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